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U. S. DEPARTMENT OF AGRICULTURE
OFFICE OF EXPERIMENT STATIONS
A. W. HARRIS, DIRECTOR

EXPERIMENT STATION BULLETIN No. 10

METEOROLOGICAL WORK

FOR

AGRICULTURAL INSTITUTIONS

MARK W. HARRINGTON
CHIEF OF THE WEATHER BUREAU

PUBLISHED BY AUTHORITY OF THE SECRETARY OF AGRICULTURE

WASHINGTON
GOVERNMENT PRINTING OFFICE
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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., February 3, 1892.

SIR: I have the honor to transmit herewith for publication Experiment Station Bulletin No. 10 of this Office, containing suggestions of meteorological work for agricultural colleges and experiment stations. This bulletin has been prepared by Mark W. Harrington, Chief of the Weather Bureau, at the request of numerous officers of the experiment stations, and will be of service in the planning and execution of much-needed investigations regarding the relations of our climate to agriculture.

Respectfully,

A. W. HARRIS,
Director.

Hon. J. M. RUSK,
Secretary of Agriculture.

SUGGESTIONS OF METEOROLOGICAL WORK FOR AGRICULTURAL INSTITUTIONS.

By Mark W. Harrington.

The institutions to which reference is here made are the agricultural colleges and experiment stations, and the work discussed is that of research, not that of education. In the broader sense there is nothing climatic or meteorologic which is not of agricultural interest, but the work which can be profitably done at the institutions above named has its limitations. The chief limitation is found in the fact that these institutions are not at the great centers of commerce, and, from the very nature of their work, can not be placed at those centers. The railroads and telegraph and telephone lines center in the great cities, while the agricultural institutions must be in the country. They can not, therefore, be made the centers for the rapid collection and distribution of information, and hence can not be made telegraphic weather stations, where the delay of a few minutes is often of vital importance. Moreover the needs of the weather map and of the forecaster require that the telegraphic stations be distributed over the entire country, in a manner bearing no relations to State areas, while the distribution of agricultural institutions depends on the individual States.

While the agricultural institutions can not generally become a part of the network of telegraphic stations, there is another line of meteorological work which they can carry on to special advantage, and this is of a more scientific character than the other; and while the telegraphic work is of transient application, the other is of permanent value. This is the work of special investigation into meteorologic and climatic problems which requires long-continued and patient observation combined with a high order of ability in planning observations and experiments and in discussing them when once made. They afford a field for the display of skill and talent which is not surpassed in any other branch of science, and the surroundings of the experiment station and agricultural college are very favorable for carrying them on. Among these are included such problems as the distribution of temperatures within such heights in the air and depths in the soil as are occupied by animal and plant life; and the changes of temperature with the hour of day, with the season, with the weather, and with the topography; the problems of

air drainage; the occurrence of frosts and protection from them; the distribution of moisture; the problems of condensation and evaporation of water in the air; the solar and terrestrial radiations and the disposition of them; the action of the meteorologic elements on organic life and the reactions of life on them; the actions and reactions of weather, climate, and soil; the precipitation of the moisture of the air and the disposition of it.

Another field which these institutions could probably occupy is that of the collection of data when no great haste is required and the mails fill the need. This is the case for general meteorologic phenomena, where the material is to be used for study, not for immediate prediction. Thunderstorms have long been studied in this way and with excellent results. The same method may be pursued for ice storms, hailstorms, tornadoes, and for secondary storms generally. To be successful, a special meteorologic service for the season must be formed by correspondence. If the area selected is small enough the observers can be so thickly scattered that no phenomenon of importance will escape them, and yet the volume of data collected will not be too large to be digested and discussed by the meteorologist of the station or college. This is a matter of great importance, and experience abroad has shown that a country like Bavaria can be covered with so close a network of voluntary observers that practically no local storm escapes them. This country should be thoroughly covered by such local and special services, especially during the warm season, when secondary storms are most common and most distinctive. The necessary expense involved is that of correspondence, postage, and clerk hire, and that of providing at least a few of the correspondents with instruments.

The investigations mentioned so far can be better carried on from agricultural institutions than elsewhere; there remains a class which contains problems often of the highest agricultural interest, but which can be conducted by any competent person who has the necessary data at his command. These are the problems of climatology, whether geographic, as of States, cities, or natural topographic areas; or of productions, as of the cotton or corn area; or of special climatologic features, as of drouths or special winds. Generally the data necessary are in the possession of the National Weather Bureau, or through its publications in public libraries, or in the hands of private meteorologists. Generally, too, they are in the libraries of the agricultural colleges. Where the necessary means exist there is no more promising field of study, and it affords the advantage of presenting collected data instead of requiring years of preliminary work in gathering them.

All the work mentioned requires the services of an accomplished meteorologist, and such services may already be found at a few of the agricultural institutions, but unfortunately such is not true in the majority of cases. The influence of weather and climate on crops is of the highest importance, and if soil physics is included in the purview

of meteorology, this subject is probably of greater agricultural interest than any other. Yet in these institutions the subjects of meteorology and climatology are usually left as subordinate topics to professors of other branches or entirely neglected. The correction of this error by the appointment of a competent meteorologist would add much to the efficiency of the agricultural work and would undoubtedly commend itself to the farmers.

The list that follows is one of suggestions of work of research proper for the agricultural colleges and experiment stations. The regular systematic observations are referred to only incidentally.

I. PROBLEMS OF TEMPERATURE.

The great problems of the geographic distribution of temperature and its changes must be studied by observations at many stations, and they form one of the objects of investigation on the part of the great meteorologic services. This is beyond the reach of the institutions whose work is here discussed. The same is true, to a less extent, concerning the distribution of temperature vertically where the heights are considerable. Agricultural institutions in or near mountainous regions can perhaps carry on observations for altitude which might be of value.

It is in the minuter problems of temperature distribution that such researches as those in question can be pursued. When there is wind enough to thoroughly mix the air, its temperature does not vary appreciably between points not far apart horizontally or vertically, especially if it is at the same time cloudy. In quiescent air, on the other hand, and especially if it is clear, there may be great differences in temperature between places that are close together. For instance, on a hot, calm, clear summer afternoon the difference of temperature over a dusty road or a plowed field or over a meadow may become very marked; and the difference in vertical distribution of temperature may be so great that an unchecked horse on the highway is in danger of sunstroke, while the checked horse is out of danger. Again, on a clear, calm night the places exposed to free radiation will have a lower temperature than those protected from radiation, so much so that plants in the first case may be frosted while those in the second escape.

On such nights as last mentioned it has been found that there is often a distinct stratification of temperatures, especially on level land. When the land is sloping, particularly in a hilly country where the slopes are considerable, the colder and heavier air flows down the slopes and pours down the valleys like water in a river, or is caught and kept in cup-shaped depressions like water in a pond. In such cases the lower levels may be frosted while the upper are untouched, and the dividing line may be very sharply defined and as horizontal as a level of water.

Such distributions of temperature play an important part in the raising of crops and deserve careful study. They depend on solar and terrestrial radiation, covering of the soil, presence or absence of shade (or

wind-breaks), slope of the ground, condensation of moisture, and evaporation, and doubtless on other things.

Observations of a direct or empirical character can be made to determine the form of the isothermal surfaces, their distances apart, and their variation with the hour of day, the general weather conditions, and the relative clearness of the air. Still better is to make, along with the preceding, studies of the physical constants involved. Solar and terrestrial radiation constants form a highly important line of observation, but require special skill and knowledge. Any one attempting them should inform himself of the refined methods now employed in the investigation of these constants. Real success in this line would at once attract the attention of physicists and astronomers. The absorption and radiation of heat by the soil, by vegetation, by organic objects on the surface of the soil, and by the gases of the atmosphere are also proper objects of study in this connection.

The sharp limits of the frost line referred to above and the occurrence of unseasonable frosts first on lowlands are due to air drainage, and this deserves careful study. The fact that plants sensitive to cold, like peach trees, can be grown on hillsides when they can not be successfully grown on levels, is due to this drainage. It is not rare on a calm morning in summer to find a difference of 10° or 15° between the river bottom and the bluffs 150 feet above. The velocity of the flow of the air, as it depends on temperature, slope, and other features, should be carefully made out. Doubtless the occurrence of fogs in the bottom lands plays an important part in air drainage.

It is claimed that frosts can be predicted with a fair degree of certainty by means of a psychrometer. When the temperature falls to the dew-point it is likely to hang there for some time before going lower, because at that point dew begins to form and the condensation of the water releases its latent heat, thus adding to the heat in the air. Consequently, if the dew-point at about 9 in the evening is above the freezing point by several degrees, the temperature will probably not fall to freezing. On the other hand, if on a night which promises an unseasonable frost the dew-point at 9 in the evening is several degrees below the freezing point it is probable that frost will occur. It is a matter of unsettled controversy whether this method of prediction can be made precise enough to really give substantial aid in foretelling frosts. Precise observations to test this should be taken at every good opportunity, and the results published to guide the raisers of tender crops, like tobacco.

The subject of protection from frosts also deserves further study. The principle involved is that smoke hinders radiation to the sky, and hence a smudge properly distributed over a field at critical times may save the crop. The question involved is this: What is the cheapest, easiest, most available, and best way of raising sufficient smoke, spreading it uniformly over a field, and adding to its density when necessary? The ordinary way of burning moist leaves is crude; that of burning tar

is better, but most farmers must provide themselves with tar to burn. There are doubtless many better ways of raising smudges known to chemists, and perhaps others which are not chemical. Experiments in this direction might prove useful.

There are many other problems of temperature which are rather biological than meteorological, but the investigation of which requires meteorological knowledge, methods, and instruments. Such are the warming of plants and especially their leaves by the sun's rays, and their cooling by radiation to the sky; the relations of insolation and temperature to transpiration and other functions of plants; and the differences of the resistance of plants to frosts. The differences in the sensitiveness of plants to heat and cold are very marked, and the coverings of plants seem to play an important part in their protection.

The instruments to be used in these investigations are exceedingly various. For some of them refined special instruments are needed. For many the thermometer and psychrometer would be sufficient. Where the observations are to be made at the point investigated the sling form of these instruments responds most readily and accurately. For weak air currents there are suitable hand anemometers or air meters.

II. MOISTURE IN THE AIR.

The moisture gets into the air by evaporation. Measurements of evaporation are not sufficiently common anywhere, but they are painfully rare in the United States. One reason for this is the difference of evaporation from different surfaces and from the same surface under different conditions. The evaporation from a water surface is less than from that of sod and different from that of bare soil and soil shaded or covered with litter. It differs also from soils of different constitutions or different colors. Moreover the same soil evaporates differently, according to its dryness or wetness, its temperature, the wind, and the moisture already in the air. The water-surface evaporation is usually taken as the typical one, but this depends on the size, shape, and material of the receiver, the level of the surface, the presence or absence of shade, and many other things. To make observations which shall be strictly comparable, evaporimeters of the same identical make must be used and the exposure must be the same. The agricultural institutions afford a particularly favorable place for observations from all sorts of surfaces, and for experiments on improved evaporimeters.

Transpiration of plants should also be measured. For meteorological purposes it is particularly important that these measurements should be taken in such a way that the evaporation from a plant can be compared with the precipitation over the surface occupied by the plant.

The moisture in the air—the absolute humidity, relative humidity, and dew-point—is usually determined by the psychrometer or dry and wet bulb thermometer, but this instrument is confessedly faulty, especially at low temperatures. The more refined methods employed in the physical

laboratory can be used, but they are tedious and only successful in the hands of the skilled observer. This meteorologic element is so important, however, especially in agriculture, that long series of the refined observations would prove of value. In investigating the relations of a surface covered by plants to the moisture in the air above it, as over turf or in and over a forest, the refined methods are necessary. The modern forms of aspiration psychrometers are to be commended.

The moisture of the air is disposed of by precipitation, direct condensation, as dew or hoarfrost, and absorption in hygroscopic bodies. The last may play an important part in tillage. A strongly hygroscopic soil may absorb moisture from the air and supply it to the rootlets of plants, thus reviving them when there is no rain or dew. There seems to be good reason for believing that a well-tilled soil is better in this respect than an ill-tilled one. Plants probably also absorb moisture directly from the air at times. These are both proper subjects for investigation.

III. CONDENSATION AND PRECIPITATION OF MOISTURE.

Dew and hoarfrost are cases of the direct condensation of moisture on objects connected with the surface. Dew forms an important source of water for plant life. In some countries its importance is very great, yet the acceptable drosometer, or measurer of dew, remains unknown. The person who will devise a good drosometer, yielding comparable results, will deserve the gratitude of meteorologists and farmers. When that is devised, systematic observations with it should be undertaken over the entire country. As it is now, not even a fair guess can be made of the annual quantity of dew, and hence we are entirely unable to make up the balance sheet for the credits and debits of water in the air. What is said of dew is also, *mutatis mutandis*, true of hoarfrost.

As to the condensation of water in free air, that is just now a favorite field for the paradoxer, and yet there is abundant opportunity for legitimate experiment and observation. It is a favorite statement of some meteorologists that water can condense on free surfaces only, and that hence the nucleus of every droplet of fog and rain, of every hailstone and snowflake is a particle of dust or smoke in the air. Aitken's results appear to prove this conclusively; but some doubt still exists about the matter because of the cleanness of rain water, the doubt if a sufficient number of dust particles are present in the upper air to start the innumerable droplets in clouds, and for other reasons. The observations should be repeated by several competent persons, but their repetition requires quite an outfit of physical apparatus. What causes condensation to begin in free air? What promotes or retards it? Does electricity play any part? These and many other questions arise, and they are all proper subjects for well-devised and carefully controlled laboratory experiments. There is no satisfactory evidence that concussions play

any part in condensation, but proper experiments, well conducted, might answer the question in the affirmative or negative.

The measurement of rainfall and other forms of precipitation has not yet become a fine art. The question of exposure of the gauge is a prime one, and although it has been extensively studied, it could be further studied with profit. What is needed is some means of correcting one exposure or form of instrument to another so as to make the results comparable. The question of wind-breaks and eddies about a gauge seems to be the important one; how important can be judged by the effects of a fence on the depth of the snow lying adjacent to it. The elevation of the gauge at reasonable distances above the ground, appears to have little effect on the catch, if the exposures are otherwise identical.

Continuous records of rainfall are important in agriculture, and instruments have been devised which, barring the question raised above, give a complete history of any shower or rain of more than two or three hundredths of an inch. These should be in operation at every agricultural institution, and for the study of minute details there should be several scattered over an experiment farm. This would give not only the record of each shower, but would also permit a study of mean hourly, daily, and seasonal rain-frequency, rain-intensity, and rain-probability.

Snow presents many features of interest on which labor could be profitably expended. Its measurement should be systematically carried on, and a given amount of each snowfall should be melted to get its equivalent in rain, thus giving what is called the density of the snow. A study of the relation of the character of the flake to the character of the weather at the time of fall might bring out many features of interest. The blizzard snow is one of the characteristic features of this phenomenon. The duration and depth of the snow have known relations to the yield of some crops. Slight falls of snow are thought to be good fertilizers. Snow also reacts on the prevailing weather in many ways, as has been pointed out by Woeikof.

Fog, sleet, and hail also present many features of interest in addition to their systematic observation. The density of the fog should be recorded on some uniform plan, as, for instance, the distance at which a slender pole can be seen in it. The size of its particles can be measured by methods given in the meteorologic text-books. The average size and usual forms of hailstones should be recorded, and especial note made of their structure and of stones of exceptional size or unusual form.

The manner in which the precipitation is disposed of is also an important matter in agriculture. How much is caught in the foliage? How much reaches the ground? How much is evaporated? What portion flows off on the surface and what enters the soil? Serious floods have occurred where with heavy rainfall a frozen soil has caused the water to flow off without penetrating the soil.

The record of cloudiness can be made by eye estimates, but a much more instructive method is that by the sunshine recorder, of which there are now many forms. This gives a fair gauge of the cloudiness for the daytime. For the night, Pickering's polestar recorder can be used; it gives even a nearer gauge of the cloudiness than does the sunshine recorder, but it requires some skill in management.

IV. CHEMICAL INVESTIGATIONS.

The chemical composition of the air varies somewhat, aside from its variable quantity of moisture. The percentage of oxygen has been thought to differ a little with the character of the weather. The investigations of Morley on this subject are the best known. The carbon dioxide varies greatly in confined places, but it is now thought that in open, free air the percentage of this gas is practically uniform. The reagent which discolors Schoenbein's test paper is generally called "ozone," but there are good reasons for thinking that there are several oxidizing agents in the air, and that the action of these is integrated in the Schoenbein test. All these features of the atmosphere deserve further study, and since it appears that "ozone" has certain biological or at least pathological relations, the tests for it should be systematically made at such stations as those here discussed.

The substances held in solution by rain and dew and those absorbed by snow are of special agricultural interest. The precipitation should be systematically analyzed, and especially a separation should be practiced between that which falls first and that which follows. The former may be expected to be richer in foreign contents.

The occasional gaseous constituents of the air are worthy of investigation, especially ammonia, nitric acid, and others useful or harmful to plants.

The measurement of foreign solid or organic bodies in the air—dust, smoke, germs, etc.—is of interest and importance in connection with agricultural science. They should be measured systematically. The best model for such work is to be found in the *Annuaire* of the Montsouris Observatory. The dusts should, when collected, be separated, chemically, microscopically, and by culture, into their different kinds. The cultures would prove especially interesting, and the modern art of studying minute germs in this way has reached a high stage of perfection. This is a field of very great interest and promise, and systematic work in competent hands would undoubtedly result in a rich harvest of results bearing on agriculture and health.

V. SPECIAL METEOROLOGIC SERVICES.

While the agricultural institutions can not profitably carry on services requiring coöperation over extensive territories, they can properly and profitably form local services, extending over a State or a

considerable part of it, for the study of the rainfall and important secondary storms. The details of rain storms are of much importance, and these can be obtained geographically by observers armed with a rain gauge and a good timepiece. For such phenomena as tornadoes, thunderstorms, ice storms, hailstorms, and the like, the gauge can be dispensed with and yet very useful results attained.

Observers for such services would be men of public spirit and enterprise, who can be found by employing the newspapers and by correspondence, and as the service is light and the prospective public benefit great, they will require no compensation. They should be scattered with all practicable uniformity over the territory covered, and should be not more than 4 miles apart on the average. This will produce as large a corps of observers as can be managed by one clerk at the central office; and few if any storms will then pass between the observers and thus escape record. The observers should be provided with blanks for record and with postage. For the rainfall observations regular returns should be made. For the secondary storms postal card blanks would be enough. One should be filled up by each observer for each storm observed, and promptly mailed to the central office. The special data required are, time of beginning, greatest intensity, and ending of the storm, so that its course can be traced over the country. To these data might well be added descriptions of the storm, of its clouds, of wind and weather before and after, and of such miscellaneous facts regarding it as may be of special interest. A thunderstorm service of this kind has been carried on for several years by the New England Meteorological Society with highly interesting results.

There should be a few stations in the territory covered which are provided with a full set of instruments—self-recording when practicable—so that a fairly complete meteorological history of the storm can be given. In local storms there is usually a sudden and short jump in the barometer record and a still greater fall in the thermometer, while the variation in direction and velocity of the wind is remarkable. These, with the automatic record of the precipitation, would form a highly interesting and serviceable record. If the record of the electric potential of the air could also be made it would be of very great interest, but these observations require an expensive instrumental outfit and a high degree of special training on the part of the observer.

Where automatic records can not be obtained, five-minute eye observations should be carried on through the height of the storm.

A somewhat different service is required for phenological observations; the territory may be much larger, the distance of the stations from each other much greater, and the reports made at longer intervals. Several widely distant agricultural institutions should establish such services over territories which would together cover the States, and patiently carry on the observations for 10 years or more. The observations should be on a uniform and carefully selected list of objects,

which should not be too large. It should include the planting, blossoming, and harvesting of the principal crops; the leafing, flowering, and fruiting of the orchard and nut trees, the heat or rut of domestic mammals, and the migrations of wild birds and insects.

It should also include the appearance of certain important fungoid diseases and insect pests of plants, where these depend on the season. The latter observations, when compiled, would easily lead to certain rules of appearance, by which it could safely be predicted that after the prevalence of such and such weather for so many days, certain plant diseases or injurious insects would be sure to appear.

One conclusion drawn from phenological observations is to the effect that with a certain accumulation of previous temperatures—the so-called thermal constant—a certain stage of plant life unfolds, that is there is a thermal constant for the flowering of winter wheat or tobacco. The theory of a thermal constant for each stage of development of such species of plants has not, on the whole, commended itself to students of the subject. It appears rather more probable that there may be a sunshine constant, that is an accumulation of a definite number of hours of sunshine for each stage of plant life. An investigation of the sunshine constants is to be recommended. Probably the relation of stages of development of plants to the accumulated weather will finally be found to be much more complicated. It is probably a function of temperature, rainfall, and sunshine combined.

VI. LOCAL WEATHER PREDICTIONS.

It is important that all means of local forecasts, independent of the weather map, should be carefully studied, and when any one is found useful it should be published in such a way as to be put at the service of those interested in it. Even those who have access to the daily weather map or who can be reached by the official forecasts can by local signs add much to the precision of the general forecasts when applied to their own vicinity. To those who can not be reached in time by the official forecasts, reliable local signs are of the highest advantage. Usually, the reliable means of local forecast vary somewhat with the place. Those for Illinois would not generally answer for Florida, nor those for New England for California. Those which are good for the western side of a mountain range would not be so significant for the eastern side, and those for a wet climate would not apply as well for a dry one. Usually the means of useful local forecasts must be found by study on the spot. This is a matter of especial importance to agricultural institutions, for the very storms which are so small as to escape the coarse-webbed dragnet of the general meteorologic service are often of the greatest importance to farmers.

It will probably be found that the special study of thunderstorms, hailstorms, and other local disturbances will result in enabling them to

be predicted at least several hours in advance, and this will be of very great service in the haying and harvesting seasons. It will probably be found, judging from the results in New England and Europe, that thunderstorms advance, in a long line, more or less directly eastward. When such a line enters the State on the western border, telegrams and telephonic messages may warn the public of its advance over the threatened district. This will have to be rapid work, for they advance with about the speed of a mail train: but a thoroughly organized system, not extended over too great a territory, may give good results at not too great an expense. A careful study of the thunderstorms over the territory in question is the first and indispensable preliminary.

A method of local prediction of unseasonable frosts has already been discussed.

The approach of rainy weather can generally be predicted many hours in advance by the use of the rain band spectroscope. A practicable form of this instrument is a small one, easily carried in the pocket. When it has been clearly shown that it reënforces our knowledge of the coming weather its use may easily become general. Systematic studies of its usefulness for this purpose should be made at all the institutions whose purpose is to make farming more certain and profitable. In critical cases a reliable indicator of coming rain, though for only a few hours ahead, might determine the saving or losing of a crop over the region threatened.

There are other instrumental means of reënforcing knowledge of future weather. The barometer is useful even to the solitary farmer, and the wind vane can also be used. There are also many familiar weather signs and proverbs, the most of which inclose a germ of truth, though some are purely poetic. The trouble with them usually is that they had their origin in distant places and other climates. Many of our weather proverbs are English or Scotch; some are from central Germany, and a few are even of classical origin and belong to the Mediterranean. These in the course of centuries have been incorporated into popular thought, and have been brought to this country by immigrants with the rest of their baggage, without reference to our differing conditions. Even at home they are sometimes of local application only. There are also a few signs and proverbs which are native. They have been derived from the aborigines, or developed by farmers and sailors on our own territory or coasts. All these should be sifted by systematic comparison with the actual weather, and proper indorsement given to those which are found to be really useful. Doubtless other new ones could be made from such data as are given by the wind-rose for each locality. The study could be pursued to especial advantage by comparing the signs with the weather map from day to day, and thus fixing each familiar phenomenon in its relation to cyclone and anticyclone.

VII. SOIL PHYSICS.

The investigations so far suggested relate to the atmosphere, and stop short at the surface of the ground. This does not fill the needs of agriculture, for the growth of plants depends on the physical qualities of the soil as well as on those of the atmosphere. Meteorology goes into the soil because of the air which the latter contains, and which varies with the weather through the temperature actions and reactions between soil and air, and because the moisture in the air comes largely from the soil, and the waters of the soil depends on the precipitation. With these problems of heat and water come those of the physical qualities of the soil—its fineness or coarseness, its color, and its composition, and these draw us back indefinitely near to the problems of origin and history of the soils. In fact modern investigations go to show that the fertility of the soil is a question of water solely, and the problems of fertilizers are simply questions of control of the flow of water through the soil and of the coagulation or condensation of the substances held in solution. Hence it would not be improper to include in these suggestions all those relating to soil physics, but for brevity, only those investigations are included which are the usual objects of ordinary meteorology.

The problems included here are those of the temperature, moisture, and flow of water in the soil. The instruments specially adapted for these investigations are not yet fully developed. The soil thermometers are the best, but several serious objections can be made to them. The ordinary instruments for the measure of moisture do not work in the soil, and those used to measure the percolation of water are confessedly very imperfect. The promising instruments for temperature and moisture are electrical. The electrical thermometers have taken several forms, all useful, and it is not easy to find a ground of preference for any one. For the measure of moisture that of Prof. Milton Whitney is the only one I have seen that gives promise of success, and it is yet in the experimental stage. The flow of water through the soil can be determined by laboratory experiments, and can be expressed mathematically for homogeneous soils. Satisfactory methods of measuring it in natural conditions seem to be still entirely lacking. There is, therefore, abundant opportunity for work in devising suitable instruments for work in the soil.

The accumulation of observations of temperature in the soil is already so great that we know its general laws. What is now needed is the study of its distribution in individual soils, and the effects on it of more or less water in the soil, of topography, and of soil covering. The study of moisture in the soil is still an almost unexplored field. As to the percolation of water, a few lysimeters (water strainers) have been used, but their results are of doubtful value. Some studies have also been made of the depth of the ground-water level and its variation

with the weather and the season. Such observations should be carried on at every experiment farm. A matter of special importance is the depth to which frost enters the soil and the occurrence and depth of continuously frozen soil. Of the latter in the United States we know almost nothing. There is reason to think that it exists in North Dakota, and that it plays an important part in the magnificent wheat crops which are grown there.

A highly important part of this line of work is to be found in the correlations between the conditions of the soil and the growth and development of individual crops. Another interesting line would be the influence exercised by tillage on the physical condition of the soil.

VIII. MISCELLANEOUS SUGGESTIONS.

The detailed climatology of each part of the country is of agricultural importance, and the institutions devoted to the development of this interest should add to our knowledge on the subject for their own localities. This would require a full set of self-recording instruments. The observations should be continued long enough to obtain good normal values—10 years, at least. These observations must be taken with very great care with instruments and exposures which will make them strictly comparable with the observations taken at the regular Weather Bureau stations. There should also be a set of standard instruments for eye readings, and the automatic registers should be checked by them. This would place the agricultural institutions in the list of those which are technically called "meteorological stations of the first order," and the surroundings of these institutions adapt them especially to this work. The exposure of the instruments can there be made unexceptionable, and the regularity of the other work carried on permits the regularity and uniformity in observation which give the best results.

There are many interesting questions in minute climatology which depend on the topography. The question of air drainage and its relation to topography have already been noted. There are many other, generally minuter, problems on which European meteorologists interested in agriculture have spent much time and labor. They relate to differences of temperature and moisture with orientation and slope.

Another and an interesting line of special meteorology is that relating to the effects of forests, and on this depend many climatal theories of unusual interest. The European literature on this subject is very extensive, and the general features of the effects of forests on climate have been determined, at least for the temperate zones. It would be interesting to repeat these for America, and there are a few features of forest influence which have not yet been satisfactorily determined anywhere. These relate for the most part to the influence of the forest on the air above it. It is also still doubtful if forests have any definite influence on rainfall. It is thought that forests do not cause so much

difference in the amount of rainfall as in its distribution. In forest regions the rainfall seems more evenly distributed through the day; cloud-bursts and torrential rains are more rare. It is also believed that hailstorms are much more unusual in forests than in open countries, and that a distinct avoidance of forests can be detected in their course. All these matters deserve more study, especially on American soil. For the climatal study of forests special devices are often necessary. The radial arrangement of stations in and about a forest is most favorable; that is with local stations in a forest there should be corresponding stations on the outside in each of the four directions. Young forests have different effects from old, and coniferous from deciduous.

In addition to the regular investigations of direction and velocity of the wind and the relation of these to the coming weather, there is another line of study which promises results of value to the farmer as well as to other classes. This is the better utilization of wind as a source of power and the application of it to such labor as the farmer has to do. The present windmills are absurdly wasteful of power and the problems of storage and application are yet almost untouched. Much the same is true of the enormous energy stored in the sun's rays. This energy is poured out in especial profusion over the farm, while the farmer has especial need of work from economical sources. A hasty but conservative estimate shows that with a very small percentage of the available energy properly stored and applied, the farmer could not only operate his farm, but could run a factory besides.

Another line of work of high scientific interest, with many possible applications, is that of the continuous record of the electric potential of the atmosphere at various heights. This, as already noted, requires elaborate apparatus and a special training, but the great scientific value of such a record would justify the expense involved.

Most of the investigations recommended so far are uncontrolled, that is they are made in free air, and the possible disturbing factors entering into them make the results rather matters of inference than of demonstration. The climatic laboratory would afford a means of controlling the observations, thus giving results which would be of a highly convincing character. This is practically a large hothouse with air-tight compartments, in each of which all the climatic and other conditions of plant growth can be strictly controlled. The temperature can be made whatever is desired; the soil, air, and water can be provided chemically pure and with just such and no more substances included as may be required. With such an arrangement rapid solutions of important problems could be made.

The study of general meteorologic problems has not been included here because the purpose has been to point out only that work which should be done at the agricultural institutions on account of its agricultural interest, and the work which could be done under more favorable

circumstances at these institutions than elsewhere. General studies could, however, be profitably taken up if a competent meteorologist were in charge and the instrumental outfit and library permitted.

One rule should be adopted in all work of the character suggested in this bulletin, and that is that the meteorologist in charge of the observations should digest them himself and prepare his results for publication. Libraries are full of published observations, and the files of observatories and stations contain many times as much material still unpublished and undigested. It is hardly worth while to add to this number. What is of use—and this may be of the highest utility—is the discussion of observations with a summary of the results to be obtained from them.

IX. OUTFIT NEEDED.

The ordinary instruments for eye observations are—

	Cost.
Mercurial barometer	$33.00
Green's standard thermometer (exposed, for wet or dry bulb)	2.75
Green's dry and wet bulb thermometers, mounted	6.50
Maximum thermometer } set, mounted Minimum thermometer }	8.25
Solar radiation thermometer	8.00
Terrestrial radiation thermometer	5.00
Soil thermometers (set from surface to 6 feet)	50.00
Anemometer	22.50
Anemometer register	22.50
Support and installation of the same ($15 to $35), say	25.00
Rain gauge and two measuring sticks	4.25
Thermometer shelter and support (standard)	35.00
Sunshine recorder (photographic)	25.00
Wind vane, standard size and supports, complete, set up	35.00

Other instruments would have to be added for detailed investigations on temperature, etc., where these studies have been decided on. Aneroid barometers are useful when frequently compared with the standards. They cost from $10 to $15. A sling thermometer or psychrometer is an ordinary one slightly changed for attaching to the end of a string. It can be whirled in an open space or can be attached to a whirling machine. Hand anemometers (air meters) cost about $25.

When the station is to be made of the first order, the following self-recording instruments must be added:

	Cost.
Barograph (aneroid)	$45.00
Thermograph	45.00
Pluviograph (Fergusson's)	50.00
Anemograph and anemo-register combined	150.00
Installation	50.00

The above prices for thermograph and barograph are for the Richard instruments. These are recommended because they are now in use

in the Weather Bureau. The Draper instruments are also good. Their prices are, barograph (mercurial) $250, thermograph $15, anemograph $175.

The Weather Bureau is using a form of recording apparatus designated the "triple register," upon which are simultaneously recorded, upon the same sheet of paper, wind direction, wind velocity, and rainfall, and improvements are now being made by which sunshine will be included. The present complete cost, including all accessories, is about $185.

For special investigations special apparatus would have to be purchased or devised. Estimates of their cost can not generally be given. For the electric work the electrometer (with complete photographic recording) would cost about $275. A magnetometer (Kew pattern) would cost about $350.

The collection of a meterological library is a large undertaking, but the following elementary suggestions can be made:

There should be obtained as complete a set of the publications of the Signal Service and its successor (the Weather Bureau) as can be found, and this should include the daily weather map when possible. The publications of the other national meteorological services (Canadian, Mexican, Brazilian, Chilean, English, French, German, Bavarian, Austrian, Italian, Russian, Japanese, Australian, and others) can perhaps be obtained by exchange.

The principal recent works on meteorology, aside from those published by the Weather Bureau, are as follows:

	Cost.
Greely, American Weather, New York, 1888	$2.50
Ferrel, Popular Treatise on Winds, New York, 1889	4.00
Blanford, Climates and Weather of India, London, 1889	3.00
Abercromby, Weather, London, 1888	1.25
Abercromby, Seas and Skies in many Latitudes, London, 1888	3.50
Scott, Meteorology, London, 1883	1.25
Davis, Whirlwinds, Cyclones, and Tornadoes, Boston, 1884	0.50
Hazen, Tornadoes, New York, 1890	1.00
Hazen, Meteorological Tables, Ann Arbor	1.00
Marié-Davy, Météorologie générale, Paris, 1877	3.50
Hann, Handbuch der Klimatologie, Stuttgart, 1883	3.75
Sprung, Lehrbuch der Meteorologie, Hamburg, 1885	2.50
Van Bebber, Ausübende Witterungs-kunde, Stuttgart, 1885	5.00
Gunther, Meteorologie, München, 1889	1.50
Mohn, Grundzüge der Meteorologie, Berlin, 1887	1.50
Woeikof, Die Klimate der Erde, Jena, 1887	6.00
Meyer, Meteorologische Beobachtungen, Berlin, 1891	1.00
Hoffmann, Pflanzen-phänologische Beobachtungen in Europa, Giessen, 1885	0.75
Ebermeyer, Die physikalischen Einwirkungen des Waldes auf Luft und Boden, Aschaffenburg, 1873	2.50
Ebermeyer, Beschaffenheit der Waldluft und die Bedeutung der Kohlensaure für die Waldvegetation, Stuttgart, 1885	0.50

The principal periodicals on meteorology are the following:

	Subscription.
American Meteorological Journal	$3.00
Symons's Meteorological Magazine, London	1.00
Das Wetter, Braunschweig	2.25
Meteorologische Zeitschrift, Vienna	5.00
Bolettino Mensuale, Moncalieri	3.00
Quarterly Journal of the Royal Meterological Society, London	5.00
Journal of the Scottish Meteorological Society	4.00
Annuaire de l'observatoire de Montsouris, Paris	0.50
Annalen der Hydrographie, Berlin	5.00

These are all monthlies except when otherwise stated. The following are periodicals which contain more or less meteorology:

	Subscription.
American Journal of Sciences and Arts (monthly), New Haven	$6.00
Science (weekly), New York	3.50
Nature (weekly), London	5.40
Philosophical Magazine (monthly), Paris	8.00
Comptes rendus (weekly), Paris	6.00
Himmel und Erde (monthly), Berlin	4.00
Ciel et Terre (monthly), Brussels	2.50
Klein's Wochenschrift für Astronomie und Meteorologie (weekly), Cöln	2.50
Wollny's Forschungen auf dem Gebiete der Agricultur-Physik, München	5.00

The publications of the St. Petersburg, Vienna, Berlin, and French Academies of Science, and the Royal Society also contain matter of meteorological interest.

The *Annuaire du Bureau des Longitudes* is an annual publication containing many physical, geographical, and other tables brought up to date. It is of great value for reference and costs about 50 cents.

The State weather services generally publish monthly and annual summaries, which can probably be obtained by exchange.

The Harvard College Observatory also publishes meteorological matter of interest.

PUBLICATIONS OF THE STATIONS AND OF THIS OFFICE.

Each station issues bulletins and annual reports, which are sent free of charge to citizens of its own State, and, so far as practicable, to applicants from other States. The work of the stations is also summarized in publications of this Office.

The Office of Experiment Stations issues two classes of publications for general distribution:

(1) Farmers' Bulletins, which are brief and popular in character, and are sent on application.

(2) Experiment Station Bulletins, Miscellaneous Bulletins, and the Experiment Station Record, which are more or less technical. It is the practice to send to persons applying for them one or more numbers, from which they may judge of their usefulness, but not to place any names upon the mailing list until after receipt of applications on special blanks furnished by the Office.

The following bulletins have been issued:

Farmers' Bulletins.—No. 1, The What and Why of Agricultural Experiment Stations; No. 2, Illustrations of the Work of the Stations.

Experiment Station Bulletins.—No. 1, Organization and History of the Stations; No. 2, Digest of Annual Reports of the Stations for 1888, in two parts; No. 3, Report of Meeting of Horticulturists at Columbus, Ohio, June, 1889; No. 4, List of Station Horticulturists and Outline of their Work; No. 5, Organization Lists of Stations and Colleges, March, 1890; No. 6, List of Station Botanists and Outline of their Work.

Miscellaneous Bulletins.—No. 1, Proceedings of Knoxville Convention of Association of Agricultural Colleges and Stations, January, 1889; No. 2, Proceedings of Washington Convention of the Association, November, 1889; No. 3, Proceedings of Champaign Convention of the Association, November, 1890.

The Experiment Station Record, vol. I, 6 numbers; vol. II, 12 numbers; vol. III, Nos. 1–7. Copies of the station and Department publications abstracted in the Record can, in many instances, be obtained on application.

Communications intended for this Office should be addressed to the SECRETARY OF AGRICULTURE, for the *Office of Experiment Stations, Department of Agriculture, Washington, D. C.*